

# APPENDIX A

## Sources of Coastal Pollutant Loadings And Related Erosion Data

Unit	Shares of total --- NITROGEN ---		Shares of total --PHOSPHORUS --		Shares of total -- SEDIMENT --		Shares of total --- BOD5 ---		Cropland Erosion Rate	Cropland's Share of All Erosion		Percent Agric. Land Needing Cons. Treatment		Region
	Agric.	Point	Agric.	Point	Agric.	Point	Agric.	Point						
0003	94.4	0.2	78.9	12.9	7.8	83.4	72.2	12.9	0.00	0.0		0.0		East
0005	0.1	0.0	0.0	0.9	0.0	34.6	0.0	0.4	0.00	7.3		55.7		East
0003	57.6	0.1	62.7	2.6	25.0	50.0	38.7	38.1	2.18	56.3		51.4		East
0002	51.9	23.9	3.9	90.7	0.1	98.6	0.7	96.6	2.11	16.3		18.4		East
0001	95.4	0.0	92.2	2.8	26.4	60.4	88.8	3.0	0.00	19.4		0.0		East
0002	76.4	0.0	76.0	0.7	53.1	29.0	75.8	0.7	0.00	13.0		53.8		East
0003	37.2	0.2	31.0	2.3	35.2	40.6	21.6	4.5	0.00	14.5		38.1		East
0001	93.6	0.0	90.6	1.2	50.1	40.5	90.0	1.2	0.71	58.7		21.7		East
0002	15.6	43.9	2.7	91.1	0.3	98.5	0.1	95.5	0.00	0.9		14.7		East
0003	87.0	0.6	67.8	17.3	14.2	70.2	46.3	18.8	4.10	61.3		59.1		East
0002	96.6	0.1	57.5	34.3	2.3	94.1	24.2	68.8	8.22	32.4		23.7		East
0004	0.0	58.1	0.0	92.8	0.0	97.9	0.0	87.5	0.00	1.4		0.0		East
0005	86.0	1.1	72.4	23.6	18.7	78.1	49.7	38.8	0.29	41.2		8.7		East
0205	79.8	0.0	65.4	1.1	40.6	36.7	64.0	1.3	6.49	79.6		37.1		East
0207	91.7	0.3	72.1	17.1	5.9	86.8	70.0	13.1	2.89	68.8		6.1		East
0001	77.8	0.1	65.9	8.6	22.8	70.9	52.8	18.1	5.34	27.8		12.5		East
0002	69.8	0.3	31.7	42.7	2.1	91.3	38.8	10.0	2.39	2.5		65.0		East
0003	64.1	1.3	26.5	54.9	4.2	89.7	8.9	77.6	17.15	73.0		12.5		East
0004	94.5	0.0	80.8	9.2	19.8	68.8	70.8	12.1	8.70	95.4		56.9		East
0005	72.1	0.0	56.7	4.9	14.9	66.6	55.6	3.0	1.85	42.3		70.4		East
0001	84.6	0.0	80.4	13.0	14.8	80.8	79.3	9.9	15.21	74.9		33.3		East
0002	79.4	0.4	85.6	9.6	33.8	63.5	51.7	38.2	0.12	0.8		18.2		East
0003	6.9	8.4	2.9	1.8	1.6	4.1	0.4	2.4	5.10	19.7		33.3		East
0004	46.0	12.1	29.5	2.6	7.2	9.9	10.2	0.4	3.48	63.3		38.3		East
0005	40.9	0.8	19.2	9.8	4.4	7.2	9.0	2.8	7.01	5.5		21.1		East
0006	52.7	41.0	71.0	2.2	18.4	15.4	11.4	77.0	2.59	12.6		33.3		East
0007	88.0	0.3	80.5	5.3	67.2	17.2	0.2	19.3	0.00	0.0		0.0		East
0003	26.2	56.3	16.9	35.0	15.0	24.7	0.2	49.3	9.72	74.2		50.7		East
0004	33.2	63.2	71.6	25.5	60.1	36.1	2.9	81.1	6.35	86.2		64.5		East
0005	0.0	3.9	0.0	0.1	0.0	0.4	0.0	0.0	8.42	73.8		42.7		East
0006	19.8	0.1	27.1	0.7	17.1	1.8	1.3	1.1	11.63	50.0		49.6		East
0007	39.4	0.6	79.9	4.1	53.4	28.8	2.9	14.1	9.75	68.8		46.6		East
0008	33.1	0.0	38.1	0.0	100.0	0.0	18.8	0.0	13.81	31.3		30.0		East
0101	0.3	42.3	25.6	5.8	14.2	22.0	0.1	6.1	7.62	3.3		60.0		East
0102	13.1	1.4	19.0	0.1	11.0	0.7	1.3	1.3	0.00	0.0		0.0		East
0103	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	0.00	2.4		2.4		East
0104	0.5	1.0	42.8	3.5	26.7	18.0	0.0	3.6	7.78	81.0		58.3		East
0105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.70	92.1		48.1		East
0201	61.0	0.0	30.1	1.6	5.2	2.2	15.0	0.3	4.27	6.3		64.3		East
0202	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	7.92	89.7		61.4		East
0102	0.0	29.9	0.0	30.2	0.0	53.2	0.0	35.1	0.00	0.0		0.0		East
0104	30.8	0.1	77.8	0.5	65.5	4.4	3.3	1.5	25.83	6.3		70.0		East
0105	99.8	0.0	100.0	0.0	100.0	0.0	100.0	0.0	7.98	69.6		49.7		East
0201	63.4	0.0	91.2	0.0	85.0	0.0	36.2	0.0	5.80	77.3		46.2		East
0202	28.6	4.5	94.2	0.0	90.6	0.1	5.8	29.7	7.30	86.3		48.6		East
0203	18.7	40.2	15.4	79.6	1.7	97.4	0.6	90.1	7.11	68.3		58.8		East

: Agricultural sources include harvested cropland, non-harvested cropland, pastureland, and rangeland. Point sources include wastewater treatment plants, powerplants, and industrial sources. Pollutant loadings used to estimate shares by point and nonpoint sources from the NCPDI. Erosion rates, cropland's share of all erosion, and percent of agricultural lands needing conservation treatment from the NRI.

nit	Shares of total --- NITROGEN ---		Shares of total --PHOSPHORUS --		Shares of total -- SEDIMENT --		Shares of total --- BOD5 ---		Cropland Erosion Rate	Cropland's Share of All Erosion		Percent Agric. Land Needing Cons. Treatment		Region
	Agric.	Point	Agric.	Point	Agric.	Point	Agric.	Point						
4	18.5	13.4	30.4	63.1	6.3	91.9	0.9	85.4	0.00	0.0		0.0		East
5	97.8	0.0	98.9	0.0	99.7	0.0	98.2	0.0	7.22	67.6		36.6		East
6	88.6	0.0	92.4	0.0	87.5	0.0	60.8	0.0	7.99	97.7		59.5		East
7	39.1	0.6	70.6	6.2	41.3	35.0	6.8	12.7	2.52	96.0		30.8		East
11	0.2	65.3	12.9	55.0	17.4	10.0	0.0	96.5	6.20	76.6		39.0		East
12	3.7	0.5	98.2	0.2	95.6	1.8	0.3	6.6	4.48	26.8		18.9		East
16	4.6	0.7	64.7	0.9	46.2	10.5	5.1	4.8	9.52	16.6		68.8		East
11	4.0	0.7	88.8	1.7	72.9	14.0	0.3	10.1	0.00	0.0		0.0		East
12	23.1	0.1	74.7	1.0	46.0	10.1	40.1	1.5	3.85	95.6		56.7		East
13	67.7	1.7	91.9	3.0	73.8	19.3	10.1	35.3	4.66	66.0		46.1		East
14	42.6	40.8	13.7	83.7	1.2	98.5	0.5	96.1	16.18	97.6		83.7		East
15	61.6	0.2	82.2	1.2	63.9	9.5	30.4	8.2	2.11	99.7		31.4		East
16	1.4	69.0	66.2	0.8	52.3	4.2	0.3	5.6	14.46	83.4		74.9		East
17	6.6	2.7	30.5	17.9	11.5	52.5	2.2	22.3	2.23	98.7		44.2		East
18	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	1.32	98.1		9.0		East
19	63.6	0.0	69.8	0.0	100.0	0.0	22.9	0.0	1.74	96.7		13.3		East
10	0.9	10.8	25.9	4.6	14.5	21.2	0.0	3.5	1.98	94.3		31.1		East
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.22	69.8		46.5		East
10	15.9	37.3	6.5	66.4	15.9	0.0	0.3	87.2	5.02	41.8		43.2		East
11	12.2	35.6	9.1	34.2	22.7	5.2	0.5	69.1	4.57	69.8		39.6		East
01	3.8	44.4	4.7	62.2	15.1	0.9	0.1	87.7	0.00	0.0		0.0		East
02	3.1	14.3	3.3	15.3	7.4	0.0	0.1	34.7	3.36	91.3		61.4		East
03	87.8	0.2	89.6	4.5	99.6	0.0	32.5	59.2	10.30	50.4		60.7		East
04	57.6	21.5	38.4	33.8	6.8	71.6	18.4	39.7	2.67	70.7		30.0		East
05	9.7	6.3	7.9	29.2	9.0	11.8	1.0	61.9	4.86	74.8		48.8		East
06	28.6	1.8	31.3	11.4	17.1	4.7	4.9	64.9	5.41	41.6		43.2		East
07	9.4	88.0	97.3	1.2	93.6	6.3	72.6	25.5	3.66	62.1		87.5		East
08	55.2	1.7	34.4	5.7	14.3	0.0	13.1	17.2	1.30	38.9		0.0		East
09	24.5	0.2	43.2	5.5	43.9	21.2	24.4	21.8	1.59	91.2		55.8		East
10	40.0	3.6	43.6	16.4	23.4	1.7	11.3	57.7	3.09	92.2		52.8		East
05	24.8	1.0	15.2	1.1	7.3	1.7	4.8	1.8	0.88	44.3		14.1		East
06	26.1	38.3	13.6	5.2	6.9	12.2	3.5	1.4	5.20	84.6		46.7		East
07	38.3	17.4	5.9	78.5	24.0	2.2	1.0	10.1	8.67	67.3		46.4		East
08	9.6	90.4	99.8	0.2	100.0	0.0	0.0	100.0	2.80	81.0		40.8		East
107	99.9	0.0	99.9	0.1	99.1	0.9	71.9	26.9	3.19	98.0		40.4		East
201	97.9	0.0	91.7	0.1	84.0	0.6	68.1	0.4	6.92	87.6		81.2		East
202	64.5	30.2	68.0	0.1	51.0	1.2	32.4	0.3	3.95	78.9		45.2		East
203	92.7	0.2	92.2	0.3	90.7	0.0	29.6	13.2	2.48	44.7		17.8		East
204	86.3	0.0	59.5	0.1	39.2	0.1	26.1	0.0	6.69	84.9		55.7		East
205	99.4	0.1	98.4	0.5	97.4	1.4	0.5	71.2	1.37	98.8		45.3		East
103	39.3	6.2	9.9	0.2	7.3	0.9	1.1	0.0	3.74	97.2		22.9		East
104	99.2	0.0	97.8	0.2	79.8	2.9	24.5	32.0	2.90	99.9		59.9		East
105	94.0	0.0	79.5	0.0	71.8	0.0	35.3	0.3	1.75	100.0		55.0		East
106	91.5	1.4	84.9	11.3	51.0	46.3	13.2	64.3	2.04	99.2		0.0		East
202	88.1	0.2	90.3	0.7	90.2	0.0	1.5	24.4	4.08	99.6		55.5		East
204	91.1	0.6	84.7	3.0	75.1	10.7	28.4	19.7	2.15	99.8		34.0		East
1001	86.1	2.1	70.0	22.3	52.8	40.7	4.5	64.8	4.78	99.3		75.0		East
1005	0.0	31.1	0.0	55.6	0.0	46.2	0.0	20.5	3.41	96.1		17.9		East
1006	0.1	75.4	3.7	0.0	3.0	0.0	0.0	0.0	3.18	98.8		57.6		East
1007	10.4	48.5	8.1	28.1	6.1	1.8	1.3	22.8	2.78	99.6		55.6		East
1201	99.9	0.1	100.0	0.0	100.0	0.0	100.0	0.0	4.82	90.7		34.5		East
1202	14.7	30.5	10.4	7.2	3.8	8.1	2.8	7.6	4.02	89.4		44.5		East

; Agricultural sources include harvested cropland, non-harvested cropland, pastureland, and rangeland. Point sources include water treatment plants, powerplants, and industrial sources. Pollutant loadings used to estimate shares by point and nonpoint sources from the NCPDI. Erosion rates, cropland's share of all erosion, and percent of agricultural lands needing conservation treatment from the NRI.

Unit	Shares of total --- NITROGEN ---		Shares of total --PHOSPHORUS --		Shares of total -- SEDIMENT --		Shares of total --- BOO5 ---		Cropland Erosion Rate	Cropland's Share of All Erosion		Percent Agric. Land Needing Cons. Treatment		Region
	Agric.	Point	Agric.	Point	Agric.	Point	Agric.	Point						
I203	7.6	30.3	6.4	3.1	3.5	0.1	1.3	7.5	0.00	0.0		0.0		East
I204	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.26	93.1		49.7		East
I205	1.9	0.8	1.7	0.2	1.2	0.4	0.1	0.8	2.86	97.9		21.8		East
I206	11.4	45.4	17.0	0.2	10.8	0.1	2.6	0.1	3.84	99.6		41.0		East
I207	0.0	39.2	0.0	0.0	0.0	0.0	0.0	0.0	2.82	96.8		100.0		East
I111	62.6	21.3	50.2	6.0	14.3	28.5	24.7	9.4	5.64	85.7		44.6		East
I112	35.9	0.4	20.2	0.7	9.5	0.2	6.4	6.7	2.98	88.4		32.3		East
I201	47.7	0.2	27.2	6.6	15.6	15.0	7.7	3.6	2.31	91.1		5.9		East
I202	0.0	48.4	0.0	38.4	0.0	75.7	0.0	25.4	3.74	69.2		68.2		East
I205	55.7	1.2	33.7	15.9	17.1	49.0	5.6	16.9	2.22	97.9		7.1		East
I206	21.5	4.3	10.7	10.3	6.0	20.9	1.4	10.5	2.46	98.8		10.2		East
I207	14.1	63.1	27.1	13.1	15.0	45.8	2.0	30.3	2.17	91.2		18.3		East
I208	74.3	0.5	46.1	3.8	37.2	6.8	9.8	3.5	1.91	89.9		12.4		East
I109	0.0	10.7	0.0	35.1	0.0	5.7	0.0	43.6	3.96	96.8		28.6		East
I202	88.7	1.0	32.3	50.3	34.2	32.2	18.7	34.3	3.62	50.0		33.7		East
I203	0.0	58.0	0.0	15.7	0.0	33.1	0.0	9.0	4.74	98.0		64.0		East
I204	59.2	13.6	7.9	12.1	6.7	21.5	0.0	23.1	1.92	0.6		0.0		East
I106	80.7	0.3	32.0	8.8	14.0	35.1	10.3	8.6	3.33	87.8		21.1		East
I201	1.8	23.3	1.2	31.7	1.3	12.0	0.1	18.1	4.50	94.9		46.0		East
I203	25.5	70.9	73.8	4.3	68.7	6.9	4.8	74.6	0.00	0.0		0.0		East
I204	0.0	52.3	0.0	83.0	0.0	9.8	0.0	66.7	1.23	10.0		76.1		East
I205	76.3	4.0	61.2	3.9	21.6	6.3	35.9	2.3	0.00	0.0		100.0		East
101	0.0	0.0	0.0	1.8	0.0	1.2	0.0	0.1	0.31	16.6		53.6		East
102	92.6	0.1	92.6	0.7	91.2	1.9	83.3	5.5	1.61	14.4		66.9		East
103	82.9	0.3	62.7	14.9	22.9	40.8	45.1	9.3	0.93	65.8		32.2		East
201	80.0	0.2	82.2	0.1	64.7	0.8	63.6	0.1	0.00	0.0		11.8		East
202	0.0	13.6	0.0	3.8	0.0	1.3	0.0	19.2	0.00	2.4		20.0		East
203	14.4	1.1	4.2	8.7	0.3	27.6	2.0	4.8	0.00	0.7		97.0		East
101	0.0	15.1	0.0	28.8	0.0	54.7	0.0	8.7	0.66	64.3		68.9		East
102	97.9	0.0	95.0	0.2	64.1	3.5	89.3	0.3	0.34	0.1		93.7		East
103	80.1	0.0	56.9	0.6	20.0	6.9	36.5	0.9	0.00	0.0		90.9		East
201	0.0	0.4	0.0	1.2	0.0	2.1	0.0	0.2	0.00	0.0		0.0		East
202	37.4	0.0	34.1	0.0	25.2	0.0	15.4	0.0	0.25	63.5		50.6		Gulf Coast
202	93.4	0.0	86.2	0.1	42.4	0.5	63.6	2.2	0.25	63.5		50.6		East
203	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0		0.0		Gulf Coast
204	0.7	0.0	0.7	0.0	0.9	0.0	0.3	0.0	0.96	72.0		66.7		Gulf Coast
205	1.0	0.0	0.7	0.0	0.6	0.0	0.5	0.0	1.14	75.4		61.4		Gulf Coast
101	2.9	0.0	1.6	0.0	0.9	0.0	0.4	0.0	0.61	0.5		37.5		Gulf Coast
102	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.00	2.6		39.8		Gulf Coast
103	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.00	3.9		62.5		Gulf Coast
201	1.9	0.0	6.4	0.0	0.6	0.0	3.1	0.0	1.35	58.7		11.5		Gulf Coast
202	25.2	0.0	9.2	0.0	1.7	0.0	4.5	0.0	1.16	70.1		52.7		Gulf Coast
203	34.5	0.0	13.8	0.0	6.4	0.0	6.1	0.0	0.68	15.0		49.1		Gulf Coast
204	0.6	0.0	0.6	0.0	0.9	0.0	0.1	0.0	2.10	0.3		26.9		Gulf Coast
205	1.0	0.0	0.4	0.0	0.3	0.0	0.1	0.0	0.00	12.1		92.6		Gulf Coast
206	0.2	0.0	0.2	0.0	0.3	0.0	0.0	0.0	0.55	37.2		60.7		Gulf Coast
207	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.13	33.5		64.5		Gulf Coast
208	7.7	0.0	1.0	0.0	0.8	0.0	0.4	0.0	1.97	59.4		80.6		Gulf Coast
208	0.0	1.2	0.0	42.0	0.0	57.2	0.0	9.4	1.97	59.4		80.6		East
101	1.0	0.0	0.1	0.0	0.2	0.0	0.1	0.0	1.89	3.2		80.4		Gulf Coast
101	0.0	69.2	0.0	0.0	0.0	0.1	0.0	18.7	1.89	3.2		80.4		East
102	16.0	0.0	2.9	0.0	0.5	0.0	2.0	0.0	0.51	62.4		31.4		Gulf Coast

Agricultural sources include harvested cropland, non-harvested cropland, pastureland, and rangeland. Point sources included water treatment plants, powerplants, and industrial sources. Pollutant loadings used to estimate shares by point and nonpoint sources from the NCPDI. Erosion rates, cropland's share of all erosion, and percent of agricultural lands needing conservation treatment from the NRI.

Init	Shares of total --- NITROGEN ---		Shares of total --PHOSPHORUS --		Shares of total -- SEDIMENT --		Shares of total --- BOD5 ---		Cropland Erosion Rate	Cropland's Share of All Erosion		Percent Agric. Land Needing Cons. Treatment		Region
	Agric.	Point	Agric.	Point	Agric.	Point	Agric.	Point						
13	84.2	0.0	82.1	0.0	38.3	0.0	74.7	0.0	6.10	88.9		58.8		Gulf Coast
11	84.5	0.0	35.1	0.0	5.2	0.0	23.6	0.0	1.44	55.7		21.9		Gulf Coast
12	99.0	0.0	95.6	0.0	60.1	0.0	91.2	0.0	4.84	97.8		52.6		Gulf Coast
13	98.1	0.0	91.1	0.0	43.1	0.0	83.4	0.0	4.78	98.4		61.3		Gulf Coast
15	89.7	0.0	30.8	0.0	13.4	0.0	27.6	0.0	0.92	93.7		18.9		Gulf Coast
16	79.7	0.0	57.6	0.0	11.3	0.0	42.6	0.0	2.42	95.5		26.9		Gulf Coast
11	74.0	0.0	47.9	0.0	6.6	0.0	31.5	0.0	3.31	87.5		27.7		Gulf Coast
13	97.6	0.0	75.2	0.0	17.8	0.0	58.6	0.0	3.23	54.8		29.1		Gulf Coast
14	93.8	0.0	43.8	0.0	8.0	0.0	26.0	0.0	6.84	86.9		50.0		Gulf Coast
11	97.0	0.0	73.7	0.0	16.5	0.0	56.6	0.0	0.99	46.5		0.0		Gulf Coast
12	99.0	0.0	89.8	0.0	37.3	0.0	80.2	0.0	4.14	80.3		54.3		Gulf Coast
13	1.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.00	0.0		0.0		Gulf Coast
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0		0.0		Gulf Coast
01	44.8	0.0	48.7	0.0	7.0	0.0	32.6	0.0	0.00	0.0		0.0		Gulf Coast
02	45.2	0.0	3.3	0.0	0.2	0.0	1.6	0.0	2.92	97.5		34.0		Gulf Coast
03	92.6	0.0	56.1	3.2	8.1	13.5	39.2	2.5	5.30	37.4		25.7		Gulf Coast
04	74.2	0.0	30.9	0.0	11.9	0.0	27.2	0.0	5.81	97.3		55.4		Gulf Coast
05	41.7	0.0	6.5	0.0	0.5	0.0	3.2	0.0	0.00	0.0		0.0		Gulf Coast
06	78.0	0.0	31.2	3.5	8.8	61.2	30.3	2.8	4.51	71.9		57.1		Gulf Coast
07	18.0	0.0	3.7	3.3	0.5	55.7	3.1	2.9	3.93	0.6		100.0		Gulf Coast
102	99.7	0.0	97.2	0.0	70.5	0.0	94.2	0.0	4.46	17.3		41.4		Gulf Coast
103	98.9	0.0	90.6	0.0	40.1	0.0	81.8	0.0	3.81	93.6		42.6		Gulf Coast
104	99.0	0.0	88.9	0.0	35.2	0.0	78.6	0.0	4.33	73.0		23.0		Gulf Coast
105	80.2	0.0	44.6	0.2	24.0	0.0	41.5	0.2	4.95	87.7		61.4		Gulf Coast
104	33.1	0.5	7.7	2.5	7.4	0.0	6.1	22.3	5.16	57.1		58.4		Gulf Coast
103	41.7	1.1	10.7	66.9	1.5	83.1	7.2	72.9	4.72	13.7		46.4		Gulf Coast
104	27.6	3.9	2.9	48.3	0.1	88.8	1.2	71.6	1.10	79.6		0.0		Gulf Coast
105	86.3	0.0	47.0	5.8	10.2	39.3	40.4	5.9	6.70	99.0		68.6		Gulf Coast
106	77.3	0.4	35.6	44.2	1.5	88.1	28.6	40.2	5.91	81.1		62.0		Gulf Coast
107	95.3	0.0	98.1	0.0	98.0	0.0	98.1	0.0	9.36	71.5		51.1		Gulf Coast
108	94.5	0.5	80.9	9.8	24.9	40.5	48.3	41.0	6.88	85.9		40.1		Gulf Coast
109	69.6	0.2	40.5	30.8	4.1	68.1	30.8	31.8	5.67	52.9		60.0		Gulf Coast
104	94.0	0.3	67.0	18.9	11.0	59.1	45.5	35.3	10.02	35.3		57.8		Gulf Coast
105	94.4	0.0	70.3	0.0	14.8	0.0	52.9	0.0	6.11	66.8		50.2		Gulf Coast
100	2.8	93.0	0.3	98.5	0.0	99.9	0.1	99.5	0.00	0.0		100.0		Gulf Coast
201	90.5	0.1	66.8	22.7	4.7	91.1	61.7	24.8	5.58	57.4		47.7		Gulf Coast
202	64.9	0.0	53.7	5.6	10.1	49.8	46.9	5.2	6.18	39.5		51.3		Gulf Coast
203	88.0	0.1	69.3	7.1	14.5	43.6	58.9	8.5	4.85	54.9		49.5		Gulf Coast
204	35.8	4.6	4.5	51.6	0.2	73.2	1.3	70.4	4.38	96.5		32.9		Gulf Coast
205	89.5	0.1	71.6	12.7	14.1	64.6	66.4	11.9	5.35	41.5		62.3		Gulf Coast
300	84.4	0.3	32.7	25.0	2.0	59.9	21.8	16.9	3.99	99.5		28.9		Gulf Coast
1101	74.7	0.6	27.5	46.8	1.1	87.0	19.9	44.8	4.68	98.5		74.2		Gulf Coast
1102	89.6	0.3	73.1	15.6	12.5	71.7	67.2	16.2	4.41	99.1		60.7		Gulf Coast
1103	92.6	0.6	37.8	51.4	1.5	92.7	34.5	45.5	3.62	95.8		78.5		Gulf Coast
1201	97.3	0.1	86.7	7.8	30.5	48.7	82.2	8.4	5.20	98.8		58.1		Gulf Coast
1202	98.3	0.0	86.9	6.0	24.8	45.6	80.1	5.7	3.38	99.4		84.2		Gulf Coast
1203	97.0	0.0	91.7	1.9	34.4	33.9	86.2	1.6	3.90	73.9		74.1		Gulf Coast
1205	76.8	0.0	81.6	1.4	45.8	5.1	76.9	1.5	2.96	81.5		63.0		Gulf Coast
1206	56.7	5.9	8.2	68.1	0.3	87.1	6.3	56.7	3.65	96.3		67.2		Gulf Coast
1100	0.0	80.3	0.0	98.9	0.0	99.9	0.0	98.5	0.00	0.0		0.0		Gulf Coast
1201	50.7	0.2	30.7	34.4	1.6	88.0	27.1	30.0	8.79	83.1		55.0		Gulf Coast
1203	0.0	4.9	0.0	70.2	0.0	88.3	0.0	54.5	0.00	0.0		0.0		Gulf Coast

: Agricultural sources include harvested cropland, non-harvested cropland, pastureland, and rangeland. Point sources include wastewater treatment plants, powerplants, and industrial sources. Pollutant loadings used to estimate shares by point and nonpoint sources from the NCPDI. Erosion rates, cropland's share of all erosion, and percent of agricultural lands needing conservation treatment from the NRI.

Unit	Shares of total --- NITROGEN ---		Shares of total --PHOSPHORUS --		Shares of total -- SEDIMENT --		Shares of total --- BOD5 ---		Cropland Erosion Rate	Cropland's Share of All Erosion		Percent Agric. Land Needing Cons. Treatment		Region
	Agric.	Point	Agric.	Point	Agric.	Point	Agric.	Point		All	Erosion	Cons.	Treatment	
1301	6.7	20.6	0.8	65.2	0.0	97.3	0.2	77.0	2.69	98.1		59.0		Gulf Coast
1302	20.9	36.7	1.5	79.7	0.0	94.0	0.5	87.7	4.18	99.7		24.4		Gulf Coast
1005	9.2	0.5	8.4	17.2	1.6	60.5	4.0	55.0	0.67	4.3		50.7		Gulf Coast
1003	35.0	7.6	0.9	77.8	0.0	92.7	0.6	70.6	0.00	0.0		2.5		Gulf Coast
1007	93.6	0.0	71.1	6.8	8.6	51.3	58.7	2.0	2.31	76.3		54.5		Gulf Coast
1202	13.9	0.0	38.3	1.9	10.0	30.6	33.5	1.8	20.82	0.9		57.0		Gulf Coast
1203	76.6	0.0	76.4	6.9	11.4	60.0	69.3	2.4	0.92	61.0		18.2		Gulf Coast
1101	36.8	1.0	2.0	65.7	0.0	89.1	2.2	21.1	0.00	0.7		73.8		Gulf Coast
1102	89.3	0.5	9.5	74.5	0.2	94.8	13.1	37.8	1.97	66.7		45.3		Gulf Coast
1103	13.0	0.5	1.2	50.7	0.0	82.0	0.9	24.9	0.00	0.0		49.0		Gulf Coast
1104	78.0	4.0	3.6	86.4	0.1	97.0	5.1	63.6	1.31	92.1		53.5		Gulf Coast
1201	91.0	0.4	37.6	44.1	1.6	86.7	26.9	44.6	0.99	92.3		17.2		Gulf Coast
1202	97.6	0.0	79.7	8.4	10.5	65.9	70.7	6.4	2.02	99.8		17.6		Gulf Coast
1203	97.4	0.8	57.6	37.1	1.6	96.1	52.1	37.5	0.77	99.5		10.5		Gulf Coast
1204	66.5	1.1	22.6	63.8	0.6	94.1	25.5	42.8	0.51	73.9		15.9		Gulf Coast
1205	70.4	0.2	53.8	29.8	3.6	85.1	51.5	20.5	0.97	87.7		5.4		Gulf Coast
1104	88.0	1.6	45.8	46.1	1.5	94.8	42.7	41.9	1.62	23.9		50.4		Gulf Coast
1302	98.2	0.0	88.6	5.8	16.9	68.2	85.6	3.1	1.29	78.4		61.2		Gulf Coast
1401	89.2	0.0	86.3	6.2	15.7	69.2	81.4	5.4	1.41	34.3		35.5		Gulf Coast
1402	92.1	0.3	56.7	32.6	3.4	87.4	56.9	20.3	0.76	55.3		75.8		Gulf Coast
1101	96.8	0.0	75.0	11.7	7.7	73.0	67.9	6.6	1.96	60.5		54.4		Gulf Coast
1102	98.0	0.0	92.9	3.0	28.8	56.8	90.6	1.9	2.49	91.5		23.2		Gulf Coast
204	69.7	1.2	19.1	55.7	0.5	90.1	14.7	44.4	4.54	11.4		26.5		Gulf Coast
303	3.3	0.0	2.0	0.0	0.0	0.0	1.3	0.0	4.87	61.6		51.7		Gulf Coast
401	93.0	1.0	88.5	4.3	23.1	56.2	84.7	2.6	1.81	72.4		56.3		Gulf Coast
402	95.7	0.1	83.3	7.8	12.2	69.1	73.5	10.0	2.02	89.5		42.4		Gulf Coast
403	2.1	0.1	7.1	1.7	2.0	24.7	3.5	45.1	0.00	0.0		0.0		Gulf Coast
404	94.0	0.0	70.7	4.1	10.5	36.7	55.8	1.7	0.00	0.0		0.0		Gulf Coast
405	69.2	0.3	21.4	26.3	0.9	67.5	14.0	12.9	0.44	3.2		86.8		Gulf Coast
406	67.9	0.0	51.5	8.5	4.8	47.3	38.3	1.1	2.57	33.4		68.6		Gulf Coast
407	88.4	0.0	82.3	6.0	13.9	61.3	76.5	2.0	2.30	90.7		91.5		Gulf Coast
111	92.1	0.0	72.3	13.6	6.7	76.7	66.0	8.4	3.80	61.5		60.3		Gulf Coast
201	78.2	0.2	38.8	36.9	1.5	87.6	32.5	28.8	1.06	76.1		88.9		Gulf Coast
202	72.9	0.4	18.7	65.1	0.6	92.9	21.5	40.0	1.22	67.0		93.0		Gulf Coast
203	6.6	0.0	8.3	0.0	0.9	0.0	4.6	0.0	1.04	16.5		100.0		Gulf Coast
204	13.5	0.0	12.0	7.1	1.9	65.9	11.2	3.1	2.72	36.4		74.6		Gulf Coast
205	71.1	0.0	83.6	0.7	46.0	24.0	81.2	0.3	2.67	34.9		93.5		Gulf Coast
206	0.8	0.0	0.2	0.3	0.2	6.2	0.2	0.0	2.67	13.3		93.5		Gulf Coast
207	0.2	0.0	0.1	0.0	0.1	0.0	0.1	0.0	2.67	18.7		67.8		Gulf Coast
208	50.1	0.3	23.1	44.6	0.8	90.9	20.3	33.9	1.81	74.1		87.5		Gulf Coast
002	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	1.56	99.3		81.4		Gulf Coast
001	50.7	8.5	20.6	21.4	3.1	44.8	11.7	9.7	0.11	6.1		38.3		West
002	82.8	0.0	80.1	1.0	56.1	6.4	68.2	0.9	0.28	0.6		31.8		West
003	27.2	35.3	14.4	5.1	2.0	7.6	6.5	8.2	0.27	0.1		47.1		West
005	96.0	1.8	96.3	1.1	23.5	75.5	69.0	15.9	0.00	0.0		18.8		West
006	99.5	0.4	96.2	3.8	87.5	12.5	77.0	22.9	0.00	0.0		100.0		West
012	37.1	61.7	60.7	33.2	33.0	60.4	40.4	36.3	3.67	24.4		85.7		West
101	100.0	0.0	99.8	0.2	98.0	2.0	97.6	2.4	0.00	0.0		0.0		West
102	92.3	2.0	92.0	5.8	87.3	4.9	54.6	41.3	0.00	0.0		0.0		West
103	96.5	0.3	95.7	0.4	93.6	1.0	45.3	25.8	0.44	1.1		32.4		West
104	85.7	3.2	51.5	27.7	29.2	48.7	12.2	57.1	0.00	0.1		23.3		West
105	100.0	0.0	99.6	0.4	97.2	2.8	96.4	3.5	0.00	0.0		0.0		West

Agricultural sources include harvested cropland, non-harvested cropland, pastureland, and rangeland. Point sources include water treatment plants, powerplants, and industrial sources. Pollutant loadings used to estimate shares by point and nonpoint sources from the NCPDI. Erosion rates, cropland's share of all erosion, and percent of agricultural lands needing conservation treatment from the NRI.

	Shares of total --- NITROGEN ---		Shares of total --PHOSPHORUS --		Shares of total -- SEDIMENT --		Shares of total --- BOD5 ---		Cropland Erosion Rate	Cropland's Share of All Erosion		Percent Agric. Land Needing Cons. Treatment		Region
	nit	Agric.	Point	Agric.	Point	Agric.	Point	Agric.						
16	8.6	81.5	10.1	88.1	1.7	98.3	0.3	98.5	0.00	0.0		92.9		West
11	99.9	0.0	99.3	0.7	92.2	7.8	97.0	3.0	0.00	0.0		0.0		West
12	98.3	0.1	76.0	21.4	39.7	58.3	55.9	21.2	0.00	0.0		100.0		West
13	99.6	0.4	98.4	1.5	99.0	1.0	78.1	21.8	0.00	0.0		64.7		West
14	99.6	0.0	99.7	0.1	99.3	0.7	99.1	0.3	0.00	0.0		70.6		West
15	6.3	2.0	47.5	2.5	37.6	11.0	0.3	24.0	0.00	0.0		70.0		West
16	89.0	0.1	53.9	8.6	21.8	38.0	24.7	8.8	0.00	0.0		62.5		West
17	99.7	0.2	92.9	7.1	56.2	43.8	82.1	17.9	0.00	0.0		0.0		West
11	96.8	0.0	98.1	0.0	93.1	0.6	94.0	0.7	0.00	0.0		91.7		West
02	99.9	0.0	99.6	0.2	98.1	1.7	98.5	0.7	0.31	0.1		88.9		West
03	100.0	0.0	99.9	0.1	98.8	1.2	99.5	0.5	0.82	17.5		46.5		West
04	100.0	0.0	99.9	0.1	99.5	0.5	98.3	1.7	0.00	0.0		0.0		West
05	99.2	0.0	99.2	0.5	83.8	14.2	98.8	0.6	0.00	0.0		30.5		West
06	3.7	0.9	2.4	7.9	0.6	70.5	2.0	19.8	0.00	0.0		69.4		West
10	25.8	1.9	10.2	43.2	0.5	97.0	7.6	53.3	0.06	0.0		83.3		West
11	40.5	0.0	59.7	1.0	37.1	33.4	58.4	2.4	0.00	0.0		92.9		West
12	5.2	0.0	5.9	0.3	5.2	9.7	5.9	0.9	0.00	0.0		100.0		West
101	6.8	0.0	8.5	1.4	6.8	36.1	6.9	5.3	0.00	100.0		1.9		West
102	4.0	0.0	5.0	0.4	4.2	13.5	4.9	0.9	0.83	11.9		40.0		West
103	1.6	0.5	2.1	3.7	1.1	54.8	1.6	20.3	0.00	0.0		5.9		West
104	38.4	0.9	15.7	36.1	0.8	91.4	14.7	23.0	0.24	5.4		42.9		West
105	1.8	0.0	4.7	1.1	3.2	32.0	4.7	2.1	0.00	0.0		0.0		West
106	13.6	64.2	2.8	64.6	2.2	11.2	1.1	64.2	0.00	0.0		0.0		West
107	0.0	10.1	0.0	6.4	0.0	0.2	0.0	19.3	0.66	12.3		45.7		West
108	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.5	0.01	0.0		48.1		West
009	0.2	1.2	3.9	13.3	4.6	0.2	0.0	0.4	0.00	0.0		100.0		West
010	88.7	0.0	71.0	0.4	34.8	0.0	49.3	0.0	0.07	0.5		63.6		West
011	3.2	2.0	4.6	18.6	0.3	5.6	0.1	46.9	0.24	15.6		32.7		West
012	42.9	1.0	41.0	1.0	31.3	5.7	9.1	11.8	0.00	0.0		88.2		West
013	49.4	0.9	21.9	34.2	8.4	62.9	3.3	19.0	0.00	0.0		54.2		West
014	42.2	25.5	16.7	40.4	12.5	47.0	2.4	48.8	0.15	0.1		78.6		West
015	26.3	16.4	7.4	73.0	2.0	91.9	0.6	76.6	0.00	0.0		88.4		West
016	95.5	2.1	94.1	0.7	84.3	6.9	65.1	3.2	0.00	0.0		100.0		West
017	82.8	1.2	62.5	2.9	39.8	20.2	18.6	4.3	0.00	0.0		100.0		West
018	52.2	31.9	44.6	15.7	26.8	38.4	1.0	94.6	0.00	0.0		0.0		West
019	91.7	0.1	53.4	9.8	14.2	46.7	27.3	9.4	0.26	7.0		58.6		West
020	98.8	0.0	99.7	0.2	98.6	1.4	95.5	3.2	0.00	0.0		66.7		West
021	97.9	0.2	96.8	0.5	94.7	2.2	70.8	5.5	0.00	0.0		57.1		West
101	97.2	2.7	82.1	17.9	76.1	23.9	25.8	74.2	0.00	0.0		66.7		West
102	0.0	0.1	0.0	2.5	0.0	9.4	0.0	1.2	0.00	0.0		0.0		West
103	99.7	0.1	96.4	3.5	79.3	20.7	81.4	18.4	0.00	0.0		0.0		West
0104	97.0	0.2	99.0	0.7	93.7	6.2	92.9	4.9	0.00	0.0		0.0		West
0105	0.0	67.5	0.0	85.4	0.0	3.7	0.0	41.6	0.15	0.0		57.1		West
0106	99.9	0.0	99.2	0.8	95.6	4.4	83.6	16.3	0.00	0.0		0.0		West
0107	21.6	0.1	13.2	3.2	6.4	13.4	1.7	1.9	0.00	0.0		0.0		West
0108	84.3	0.0	77.5	1.7	48.3	7.1	53.2	2.9	0.00	0.0		5.3		West
0109	12.2	0.3	15.3	2.5	13.3	7.1	0.5	1.4	0.00	0.0		0.0		West
0110	97.7	0.1	85.9	8.5	70.2	23.0	67.2	18.6	0.00	1.2		9.8		West
0111	16.3	0.0	15.6	0.0	8.5	0.0	9.6	0.0	0.00	63.1		100.0		West
0209	99.4	0.0	99.8	0.0	100.0	0.0	99.2	0.0	0.00	0.0		0.0		West
0212	17.8	0.1	51.1	4.7	60.7	34.7	19.3	16.0	0.00	0.0		100.0		West
0214	83.4	13.9	70.3	19.9	84.0	1.5	4.2	93.1	0.00	0.0		0.0		West

:: Agricultural sources include harvested cropland, non-harvested cropland, pastureland, and rangeland. Point sources include  
 wastewater treatment plants, powerplants, and industrial sources. Pollutant loadings used to estimate shares by point and nonpoint  
 sources from the NCPDI. Erosion rates, cropland's share of all erosion, and percent of agricultural lands needing conservation treat-  
 ment from the NRI.

o Unit	Shares of total		Shares of total		Shares of total		Shares of total		Cropland Erosion Rate	Cropland's		Percent Agric.		Region
	--- NITROGEN ---		--PHOSPHORUS --		-- SEDIMENT --		--- BOD5 ---			Share of		Land Needing		
	Agric.	Point	Agric.	Point	Agric.	Point	Agric.	Point		All	Erosion	Cons.	Treatment	
0109	86.9	8.7	90.4	9.4	89.3	10.7	1.3	98.6	0.78	76.4		22.5	West	
0111	99.9	0.0	100.0	0.0	100.0	0.0	99.6	0.3	0.81	37.1		0.0	West	
0117	96.8	0.3	77.5	21.5	12.3	87.7	51.1	47.8	0.00	0.6		92.9	West	
0002	25.0	0.0	78.6	0.4	91.0	5.8	24.0	1.6	0.15	48.7		26.5	West	
0003	93.2	6.6	93.7	6.3	84.9	15.1	4.9	95.1	0.08	1.0		31.0	West	
0004	56.0	41.5	98.3	1.5	98.1	1.9	0.1	99.8	0.34	1.1		10.9	West	
0005	53.9	0.0	43.8	3.9	25.7	33.0	22.6	4.4	0.37	32.9		11.2	West	
0013	3.4	9.2	24.4	2.3	17.2	13.3	0.2	1.2	0.00	27.9		51.5	West	
0001	98.3	1.6	98.8	1.2	94.2	5.8	13.6	86.4	1.27	7.1		15.8	West	
0002	95.9	0.0	97.2	0.0	98.7	0.7	95.9	0.0	0.00	2.0		13.6	West	
0003	96.5	0.0	74.9	0.2	51.8	2.5	50.5	0.2	0.74	0.1		28.6	West	
0004	55.8	40.7	95.6	0.2	94.8	4.3	93.8	0.2	7.32	1.6		61.9	West	
0005	95.3	4.2	92.4	7.6	90.7	9.3	3.8	96.2	0.00	0.0		0.0	West	
0006	32.6	18.8	12.6	15.3	7.3	8.5	3.6	11.9	8.64	4.6		66.7	West	
0001	0.0	0.1	0.0	0.0	0.0	0.0	0.0	1.4	10.80	2.3		80.0	West	
0002	24.3	0.5	15.8	5.2	24.3	18.2	3.9	3.6	2.72	2.6		18.7	West	
0003	0.0	0.1	0.0	0.1	0.0	0.2	0.0	0.0	15.10	100.0		31.3	West	
0004	0.0	0.1	0.0	3.9	0.0	14.4	0.0	2.0	4.53	11.9		33.8	West	
0005	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	6.16	20.5		57.1	West	
0006	1.6	69.2	0.0	99.9	0.0	100.0	0.0	99.9	2.00	0.0		44.4	West	
0007	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.2	0.17	0.1		0.0	West	
0008	0.0	11.9	0.0	95.4	0.0	5.6	0.0	71.9	0.33	0.0		0.0	West	
0009	16.8	0.3	2.5	0.6	0.2	2.4	1.2	0.3	0.66	93.5		46.7	West	
0010	57.0	0.0	19.4	0.0	1.6	0.0	9.9	0.0	3.65	0.9		24.1	West	
0011	0.0	5.1	0.0	1.7	0.0	6.5	0.0	0.9	1.86	52.6		58.2	West	
0012	0.0	9.0	0.0	84.5	0.0	81.8	0.0	32.9	0.00	0.0		0.0	West	
0013	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.00	16.7		53.8	West	
0014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0		0.0	West	
0101	0.0	4.9	0.0	3.6	0.0	12.9	0.0	1.7	52.69	64.9		65.5	West	
0102	0.0	0.7	0.0	3.1	0.0	7.6	0.0	2.6	0.67	0.1		3.8	West	
0103	88.2	0.0	66.4	1.0	75.3	4.0	23.9	1.5	0.94	34.6		32.5	West	
0104	22.5	0.0	13.8	0.1	27.9	0.7	2.4	0.1	0.00	0.0		0.0	West	
0105	0.0	3.4	0.0	89.4	0.0	0.0	0.0	24.6	0.00	0.0		0.0	West	
0106	0.4	2.3	0.5	6.5	0.7	65.3	0.2	43.0	0.00	1.7		0.0	West	
0107	34.8	3.2	13.4	21.8	3.2	79.5	5.3	57.3	0.00	0.0		0.0	West	
0201	29.1	1.7	30.4	15.5	5.8	74.9	24.3	27.2	0.00	0.0		0.0	West	
0202	0.5	2.4	0.9	5.4	1.1	54.4	0.3	39.0	0.61	15.1		12.1	West	
0203	72.3	4.5	42.4	45.2	7.0	87.4	7.9	73.1	0.28	0.2		36.6	West	
0204	0.1	0.1	0.1	1.1	0.1	24.7	0.1	5.8	0.00	17.7		100.0	West	
0301	8.8	1.9	5.9	47.8	0.2	95.6	3.2	63.5	0.68	0.0		46.2	West	
0302	1.2	5.3	0.3	40.7	0.0	80.7	0.1	48.3	0.51	36.5		48.0	West	
0303	1.9	2.6	2.7	31.0	1.4	89.4	0.5	52.9	0.82	6.4		38.5	West	
0304	5.3	0.2	4.4	1.8	3.6	43.6	3.8	7.6	1.78	0.1		11.8	West	
0305	8.0	2.0	4.2	22.6	0.5	86.3	2.1	45.6	0.08	0.0		0.0	West	

: Agricultural sources include harvested cropland, non-harvested cropland, pastureland, and rangeland. Point sources include wastewater treatment plants, powerplants, and industrial sources. Pollutant loadings used to estimate shares by point and nonpoint sources from the NCPDI. Erosion rates, cropland's share of all erosion, and percent of agricultural lands needing conservation treatment from the NRI.

**Integrating Economic and Physical Models for Analyzing  
Environmental Effects of Nonpoint-Source Pollution**

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## 1. Introduction

Public concern over environmental issues has increased dramatically over the last two decades and agriculture has not escaped this environmental scrutiny. The impact of agricultural practices on resource quality and, in particular, on ground and surface water quality has received both political attention and public research dollars. One of the critical issues to be faced by policy makers is how to design institutions that protect environmental quality and are compatible with productivity growth. Such policy design requires, as we argue in this paper, a synthesis of research from social and physical scientists to identify and quantify the magnitude of the social benefit and costs associated with current agricultural practices in relation to environmental quality.

There are at least two reasons why, in the past, analysts have tended not to include the environmental and health impacts in their analyses of returns to agricultural research or in their evaluation of specific policies or programs: deficiencies in methodology and data. On the methodology issue, a comprehensive analytical framework is needed which combines field-level relationships among management practices, environmental attributes of the farmland, and nonpoint pollution with impacts on human health and the ecosystem. The research from various disciplines (physical, biological, economic, and health sciences) needs to be integrated into an analytical framework that, to be useful for policy analysis, makes the link between the physical changes in environmental and resource quality attributable to agricultural practices, and the valuation attached to the changes in environmental quality and the subsequent impacts on human health. With respect to data deficiencies, the concerns are in two related areas: the information needed to quantify the environmental quality and agricultural production relationships has generally not been available; and the data on health effects of exposure to agricultural chemicals are far from complete.

This paper begins to address these deficiencies, first, by developing an approach to integrating disciplinary research to quantify and value the impacts of agricultural chemical use, and second, by highlighting the data requirements for this research. The approach is illustrated using the issue of chemical contamination of groundwater.

Pollution of groundwater by agricultural chemicals is often categorized as a nonpoint-source pollution issue. Tietenberg offers the following distinction between point and nonpoint sources of water contamination: "Point sources generally discharge into surface water at a specific location through a pipe, outfall or ditch, while nonpoint sources usually affect the water in a more indirect and diffuse way" (p. 406). The control of nonpoint-source pollution has, until recently, received relatively little theoretical or empirical attention. The recent presidential Water Quality Initiative and its focus on agricultural sources of water pollution has helped focus policy and research interest on this problem.

In effect, the approach taken in this paper is to transform the nonpoint-source problem into a more manageable point-source problem. This is done by using a well-defined distribution of characteristics for a large number of heterogeneous sources (or fields) to simulate how much of a given chemical will reach an environmental medium. The link between the characteristics of the sources and the quantity of pollution is made using the chemical fate and transport models. Thus, one unique feature of the framework we propose is the integration of the physical science models, which deal with what occurs at the specific points of chemical application, with the policy models that need to effectively deal with a collection of heterogeneous points. Similar approaches have been used for air pollution control models. However, an important modification for the groundwater pollution problem is the need to model the movement and changes in composition of the chemical from the point of discharge (application) to the point of entry into the groundwater aquifer.

Benefit cost analysis (BCA) provides the framework in which to organize a coherent approach to incorporating environmental and health costs into public policy analysis and for addressing the uncertainties inherent in this type of analysis. The BCA process for addressing the environmental and health impacts of pesticide use is presented in Figure 1. The first step is to determine the effect of the policy or the change in technology on the output and input decisions of the farmers; the second step is to quantify how a farmer's response affects the magnitude of the benefits and costs. In the case of a pesticide use reduction, changes in environmental contamination, food residues, and occupational exposure give rise to the benefits; the effects on production and resource use determine the costs.

The environmental impacts of changes in pesticide use depend on the physical processes of pesticide transport through soil and water mediums and subsequent contamination of secondary food sources. Analysis of the effects of changes in pesticide use on human health involves both human and environmental risk assessment.

The third step is to express the benefits and costs in a common unit that reflects their valuation by the affected individuals. The valuation of the costs of the pesticide use restrictions or changes in production technology can be measured as changes in producer and consumer surpluses or related welfare measures. The valuation of the benefits involves predicting the impacts on the environment and estimating nonmarket values.

The final step in the BCA process is the determination of the net impact on social welfare. This requires a criterion for determining what qualifies as an increase in welfare, and a means for aggregating the impacts which may occur at different points in time and impact different groups of individuals.

The remainder of the paper is organized as follows: section 2 presents an overview of the characteristics of the physical models that can be used to predict the movement of

chemicals in soils and discusses a prototype model for assessing pesticide concentrations in the soil and groundwater. In section 3 attention is focused on modification of economic production models. Section 4 addresses the methodological issues that arise in integrating physical and economic models for use in the benefit-cost framework.

## 2. Physical models for quantifying contamination levels

Physical models for quantifying chemical pollution externalities need to address movement of chemicals to both surface water and groundwater. In the last three decades an extensive literature has been generated by research aiming to trace the movement of surface water contaminants. Climate, watershed and soil characteristics, and crop management practices have been found to affect the magnitudes of the impacts (see Jury et al., 1987).

Concern over groundwater contamination is a relatively recent development and, as a result, models that predict chemical leaching to groundwater are less developed than models that predict chemical runoff to surface water. To predict potential loadings to groundwater, a model is needed to trace the movement of the chemical from the application site down through the unsaturated zone and into the saturated zone. The saturated zone is the area in which all the void spaces are filled with water; in the unsaturated zone, the void spaces are filled with both air and water, the proportion of which is important in modeling transport rates.

The fate of a chemical applied to soil depends on the pesticide's properties. Persistence is a measure of a chemical's rate of degradation and is usually measured in terms of a chemical's half-life. Solubility, sorption, and volatility determine how a compound partitions among water, soil, and air phases and affect whether the chemical is moved primarily with sediment or water. When a pesticide is applied, some of it will adhere to the organic carbon in the soil particles; this is called adsorption. Some of the pesticide will mix with soil water

and move down with the soil water. An inverse relationship exists between the solubility of the pesticide and its sorption to soil. A partition coefficient value is used to describe the ratio of pesticide concentration in the adsorbed phase and the solution phase. The smaller the partition coefficient, the greater the concentration of pesticide in solution. Hydrologists have noted that the greatest threat to groundwater through leaching is associated with a pesticide with a small partition coefficient and a long half-life.

## 2.1 Chemical transport models: An overview

Although the specific structure of the chemical fate and transport models vary, most models contain some standard components. These include:

(i) Surface runoff generation component: describes the transformation of precipitation into runoff. The soil surface and profile provide major controls on the response of the surface-water system. During interstorm periods, pesticides may be applied and undergo a variety of transformation and degradation processes affecting the total mass of each constituent available for entrainment and transport. Land-use practices such as tillage affect the infiltration, runoff, and erosion processes. The processes composing the surface-runoff system are hydrology, sediment, nutrients, and pesticides. (A detailed presentation of modeling surface runoff is provided by Beasley et al., 1989.) The USDA Soil Conservation Service Curve Number (SCSCN) model is commonly used to estimate runoff. This method relates direct runoff to daily rainfall as a function of a curve number representing soil type, soil drainage properties, crop type, and management practice.

(ii) Soil and groundwater component: describes chemical movement through the unsaturated soil zone and may also describe movement into the saturated zone. Not all models trace the movement of chemicals through the unsaturated zone to the saturated zone.

(iii) Erosion component: estimates soil loss due to erosion. This is important when determining potential for groundwater contamination because soil sediment is a medium of transport for adsorbed pesticides. A pesticide or nutrient that is transported off the field via eroded soil is not available for leaching to groundwater. The Universal Soil Loss Equation (USLE), or a modification of the USLE, is frequently used to model erosion. The USLE accounts for factors such as rainfall, crop management, slope conditions, and erosion control practices in calculating soil loss per acre.

(iv) Soil adsorption and desorption component: estimates the partitioning of a chemical between adsorbed particles and dissolved chemicals. This component estimates what portion of the chemical may be transported by soil sediment and what portion may be transported by soil water. It may also model volatilization and decay of the chemical.

Chemical transport models can be divided into three broad categories: research models, screening models, and management models (Wagenet and Rao, 1990, provide a detailed discussion of these models). Research models provide quantitative estimates of water and solute movement, but usually involve extensive data demands on the system to be simulated. Management models are less data intensive, and less quantitative in their ability to predict water and solute movement under various environmental conditions. Although most managerial and research models are field scale models, Wagenet and Rao indicate that there has been limited field testing of either the research or management models to date, and thus little attention has been focused on the so-called management models for the actual purpose of managing pesticide or fertilizer usage. The existing research models are useful for management purposes only if computer facilities and time are virtually unlimited.

Screening models are used to evaluate and compare pesticide fate and transport under alternative environmental conditions. The screening models have relatively low data demands,

and are designed to be relatively easy and inexpensive to use. One useful output of these models is to categorize chemicals into broad behavioral classes. These models have relevance in the pesticide registration process, where the properties of a pesticide which has not been field-tested can be inferred from the class in which it is placed. Several simple indexes useful to screen and rank pesticides in terms of their potential to leach into groundwater have been developed by Rao et al., 1985. These ranking schemes are based on a screening model which determines the relative travel time needed for the pesticide to migrate through the unsaturated zone, and the relative mass emissions (loadings) from the unsaturated zone into the groundwater.

Jury et al., 1987, have also developed a screening model of the pesticide leaching process. This model relaxes the uniform first order decay assumption for pesticide degradation in the unsaturated zone which characterizes the Rao et al., 1985, model and replaces it with a biochemical decay relationship which decreases with soil depth. The results of both screening models indicate a significant dependence on site-specific soil and environmental conditions, suggesting that these factors, as well as the pesticide properties, need to be taken into account when screening for groundwater pollution potential.

Wagenet and Rao caution against using existing screening models to predict environmental changes. They indicate that the recent interest in using models to predict the fate of pesticides in water and soils has provided an impetus to improve upon the accuracy of both screening and research models. One of the most promising avenues to proceed for developing policy models is condensing the comprehensive descriptions provided by research models. Examples of such an approach are the recent changes to the PRZM and LEACHM models (see Wagenet and Hutson, 1987) and the Jury et al. (1987) model and the prototype model discussed in section 3.2.

## 2.2 A simple Pesticide leaching model

One major disadvantage of the large scale research simulation models is their lack of attention to the movement of chemicals through the unsaturated zone, although groundwater components have recently been appended to some models. A second disadvantage of these models is simply the size and data requirements. Most utilize daily and often hourly climate data to simulate chemical movement.

As an alternative, researchers have been developing screening models to evaluate pesticide groundwater pollution potential (Jury et al., 1987; Rao et al., 1985). This approach is promising for use in regulatory BCA, and thus we illustrate the integration of such a model into the net benefit specification.

Two key variables in assessing the behavior of chemicals as they leach into groundwater are pesticide residence time and the fraction of the pesticide remaining as functions of depth in the unsaturated zone. Physical relationships can be used to estimate residence time,  $t_i$ , and the time required for a pesticide particle to travel from land surface to the depth of interest,  $z_i$ , as a function of physical parameters such as: water flux per unit surface area; residual moisture content; dry bulk density; the organic-carbon partition coefficient of the pesticide and the percentage of organic carbon in the layer.

The fraction of the pesticide remaining at the depth of interest is calculated taking into account both the decay and root uptake processes. The fraction of the pesticide that remains after decay that occurs during its transport through each soil layer can be calculated by solving the equation for irreversible first-order reactions allowing for the known half-life of the pesticide:

$$(1) \quad r_i = e^{-0.693 (t_i/h_i)}$$



where  $r_i$  denotes the fraction of the pesticide remaining after transport in the  $i$ th layer;  $t_i$  denotes the time of travel (residence time) in the layer of interest, in days; and  $h_i$  denotes the half-life of the pesticide in the layer, in days.

These latter values are assigned to each layer in the system based on empirically obtained figures from field and laboratory experiments. The percentage of the original pesticide applied to the land surface that remains after transport through more than one layer is the product of the values of  $r_i$  for each layer. The percentage of the pesticide remaining after transport and decay through all layers is then

$$(2) \quad r_z = \prod_i r_i .$$

The key parameters in determining the amount that remains generally are half-life of the chemical, porosity, partition coefficient (which is determined by the organic-carbon coefficient of the pesticide, and the percentage of organic carbon in each layer), water flux, and water content.

The root uptake process also must be estimated, and as a first-order approximation, can be assumed to be proportional to the root uptake of water, evapotranspiration. To obtain the fraction of the pesticide remaining after these two processes (root uptake and decay) have occurred, the amount of pesticide remaining after decay is multiplied by the ratio of the amount of water flux at the depth of interest to the amount of water entering the ground at land surface:

$$(3) \quad C(X_j) = (r_z)(q/w)(X_j)$$

where  $q$  denotes water flux per unit surface area,  $X_j$  denotes the amount of pesticide applied, and  $w$  denotes the rate at which water enters the ground. Equation (3) could be incorporated into a net benefit analysis as illustrated in section 4.

To utilize this kind of model, information would be required on soil (physical) and pesticide characteristics. The soil characteristics include the rate at which water enters the ground; the rate of deep percolation below roots; the thickness of the root zone; the depth to water table; and the density of solid matter in the unsaturated zone. Other layer-specific physical characteristics include the type of material; the residual moisture (water) content; the porosity; and the organic carbon content of the soil. Pesticide characteristics of importance to these models are organic-carbon partition coefficient; and the half-life in each layer. In addition, data on pesticide applications are also needed. Of the above information, only the pesticide application levels and the amount of water entering the ground at time of application would need to be collected each period.

### 2.3 Environmental Exposure Modeling

More general approaches to environmental quality modeling are also being developed. The standard approach to modeling environmental exposure is to assume that chemicals are distributed into various environmental compartments as functions of chemical properties, environmental factors, and chemical use according to equilibrium partitioning models (Mackay et al., 1985). For example, it may be assumed that a pesticide applied to a field will be partitioned among air, water, soil, flora, and fauna. Symbolically,

$$C_{ij} = C_i(X_j, K_{ij}, E_i)$$

where:

$C_{ij}$  is the concentration of the  $j$ th chemical in the  $i$ th partition;

$X_j$  is chemical use;

$K_{ij}$  is the partition coefficient; and

$E_i$  is a vector of environmental factors.

The environmental contamination in each partition can be translated into exposure of the  $k$ th species through the expression

$$e_{jk} = \sum_i C_{ij} A_{ijk}(\gamma)$$

where

$e_{jk}$  is the exposure of the  $k$ th species to the  $j$ th chemical;

$A_{ijk}(\gamma)$  is the rate of uptake of the  $j$ th chemical in the  $i$ th partition by the  $k$ th species; and

$\gamma$  is a vector of individual species characteristics.

Thus, in general total exposure of the  $k$ th species to the  $j$ th chemical is a function  $e_{jk}(X, K, E, \gamma)$ , where the arguments are vectors of chemicals used, partition coefficients, environmental characteristics, and species characteristics. These exposure measurements can in turn be valued and used in BCA.

### 3. Economic Production Models

The economic behavior of agricultural firms can be represented as a two-level decision process corresponding to the short-run and the long-run (Figure 2). In the short-run, firms make production decisions regarding outputs (types of crops and allocation of acreage among crops) and variable inputs (such as labor hours, fertilizer applications) taking as given the available technology and the existing stocks of physical capital and other resources used in production. These short-run decisions may be important in the analysis of externalities because they may include the use of agricultural chemicals which are a source of pollution. In the long-run, firms make investment decisions based on their expectations of future market conditions, technology, and resource availability. Their long-run decisions include the total acreage of the farm operation and the quantities of physical capital employed. The long-run decisions may also have important consequences for externality generation. For example, the

choice of tillage method (conventional tillage versus reduced or no-till) may have an impact on soil erosion and herbicide use, and hence on pollution caused by chemical runoff.

### 3.1 Producer behavior in static models

The analysis using a static model focuses on the output and input decisions that are made in each production period, given technological, economic, and resource constraints. Farmers are assumed to be concerned with the private benefits and costs of their farm operations, and thus do not take into account the longer-term impacts of their production activities on the ecosystem or on human health caused by agricultural pollution that occur off their farms. For the measurement of externalities, the effects of the output and input decisions on physical resource stocks and living organisms in the ecosystem can be quantified. To measure the sequence of externalities generated over time, the biological system's changes can be incorporated into the economic model to define the resource constraints on production in the next period, and the analysis can be repeated.

The short-run economic behavior of an agricultural producer can be modeled in terms of profit maximization; more generally risk management and other objectives can be introduced, but as a first-order approximation, profit maximization is a useful starting point. Analysis of the profit-maximizing firm is based on the representation of the production process using the production function

$$Q_t = f(X_t, Z_t, \tau_t, R_t, S_t)$$

where  $Q_t$  is the maximum rate of output that can be produced in period  $t$  with variable inputs  $X_t$  (generally, a vector measuring labor, fertilizer, pesticides, etc.), fixed (capital) inputs  $Z_t$  (a vector measuring land, structures, machinery and tools, etc.), and parameter  $\tau_t$  representing the state of the technology (traditional seed variety versus modern seed variety, for example).

The role of physical and biological resources in the production process is represented by the vectors  $\mathbf{R}_t$  (physical resources) and  $\mathbf{S}_t$  (living organisms) in the production function. The vector  $\mathbf{R}_t$  could measure physical attributes of the resources used in production, such as soil and water quality, and the vector  $\mathbf{S}_t$  could measure populations of pests and natural enemies to pests.

The profit maximization problem is represented as

$$\max \pi_t = P_t f(X_t, Z_t, \tau_t, R_t, S_t) - W_t X_t$$

where  $P_t$  is the price of output and  $W_t$  is a vector of prices corresponding to the elements of  $X_t$ .

By assuming that the production function is concave in the variable inputs  $X_t$ , the dual restricted profit function,

$$\pi_t = \pi[P_t, W_t, Z_t, R_t, S_t, \tau_t],$$

can be defined as the maximum profit the firm can earn, given  $P_t$ ,  $W_t$ ,  $Z_t$ ,  $\tau_t$ ,  $R_t$ , and  $S_t$ , by choosing levels of output and variable inputs. A property of the profit function is that the firm's profit-maximizing output,  $Q^*$ , and its profit-maximizing input vector,  $X^*$ , satisfy the following relationship:

$$Q_t^* = \partial \pi[P_t, W_t, Z_t, R_t, S_t, \tau_t] / \partial P_t = Q^*[P_t, W_t, Z_t, R_t, S_t, \tau_t]$$

$$X_t^* = -\partial \pi[P_t, W_t, Z_t, R_t, S_t, \tau_t] / \partial W_t = X^*[P_t, W_t, Z_t, R_t, S_t, \tau_t]$$

The complete production model is represented by the system of the three previous equations. Since the first equation measures short-run profit, it can be interpreted as measuring the producer surplus (net returns) used in BCA. For example, if a new seed variety was introduced, but prices, physical capital, and resource stocks were constant, the profit function would indicate the resulting change in producer surplus attributable to the new seed variety. The equation system also shows that the introduction of the new seed variety would